HIGH POWER PULSE MODULATOR FOR PLS LINAC*

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Abstract

Complete design, assembly, and testing of 200 MW modulators are in progress at Pohang Accelerator Laboratory (PAL) for the full energy injection linac system of the Pohang Light Source (PLS). A 150-MW pre-prototype modulator (350 kV, 3.5 μs flat-top width, and 840 Ω load) has been assembled and tested up to 175 MW. Design, construction, and test of a 200-MW prototype modulator (400 kV, 4.4 μs flat-top width, 800 Ω load) has also been completed. Eleven units of main 200-MW modulators are under construction, and their assembly is expected to be completed in 1993. This paper presents the design and the current status of performance results of 150-MW and 200-MW modulators.

I. INTRODUCTION

The specification of the full energy injection linac system of the PLS requires total eleven units of 200-MW modulator and 80-MW klystron [1]. A 150-MW pre-prototype and a 200-MW prototype modulators are already constructed. Preliminary results of the 150-MW modulator is presented elsewhere [2]. Currently the 150-MW modulator is installed in PLS test laboratory. The 200-MW prototype modulator is installed in linac gallery and tested up to 145-MW beam power with a 80-MW Toshiba klystron. Eleven main 200-MW modulator units is under parallel construction in PAL and is expected to be completed this year.

II. MODULATOR PERFORMANCE AND CONFIGURATION

A plot of beam voltage versus E-3712 klystron RF output power is shown in Fig. 1. The 150-MW pre-prototype modulator is used to take the data shown in the figure. A Toshiba E-3712 klystron with an 1:17 turns ratio pulse transformer is used as a load. A SLAC RF water load is installed to absorb the RF output power of the klystron during the test. As shown in the figure, maximum 175-MW beam power (i.e., 375 kV beam voltage) is applied to the klystron load. A peak power capability of a thyratron (ITT F-241) in the 150-MW modulator is 125-MW. Therefore, the tested peak beam power is much higher than the ITT's specification. The 150-MW modulator will be continuously used for the purpose of conditioning high power klystrons. Specifications of the 200-MW modulator are listed in Table 1. It shows required parameters of current PLS linac, designed parameters for future upgrade, and tested parameters. The 200-MW modulator test is done using a water dummy load (250 kV max. at10 Hz) as well as a E-3712 klystron load. Modulator test with a E-3712 klystron which is connected to the linac waveguide and accelerating column is also successfully done.

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Table 1: 200-MW modulator specification

Description	Required	Designed	Tested
Peak power (MW)	200	200	145
Ave. power (kW)	97	289	33
Peak output volt. (kV)	400	400	357
Rep. Rate (PRR) (Hz)	10 to 60	180 max.	30
ESW (μs)	---	7.5	7.5
Flat-top width* (μs)	4.4	4.4	3.0
Charging time (ms)	---	5.76 max.	5.76

* less than ± 0.5 %.

Electron beam energy of 200-MeV is actually extracted by using the 200-MW modulator and 80-MW klystron unit along with a 60-MeV preinjector section. The 145-MW tested power in Table 1 is limited by the progress of solid RF load power conditioning. Full required parameter test of the 200-MW modulator at 14 Hz will be performed with a solid dummy load that is currently in fabrication, and the result will be reported in the near future.

Table 2: Specification of major parts in 200-MW modulator

SCR	700A rms, 400A ave., 1,600V	
3φ transformer	440V rms, 19kV rms, 12A rms, 98% eff.	
Rectifier diode	48 (1600V, 25A ave.) in series per arm.	
Filter choke	5 H min. at 15A DC	
Filter capacitor	3 (4.7 μF,30 kV) in parallel, total 14.1 μF	
Charging inductor	Primary	2.4 H, 11A DC
	Secondary	1:25 ratio, 55A DC, 2 kV
Charging diode	80 (1600V, 95A DC) in series	
Despiking circuit	L	min. 14 mH at 11A DC
	R	2 kΩ
EOLC	Diode	same as charging diode
	Resistor	4 (10 Ω, 70 W) in parallel
	Thyrite	32 (275V DC, 10 W) in parallel
PFN	C	total 28 (50 nF, 50 kV)
	L	total 28 (4.5 μH max.)
Thyratron	ITT F-303	
Triaxial Cable	Double	
Pulse Transformer	1:17 ratio, >96% efficiency	

Fig. 2 shows a simplified circuit diagram of the 200-MW modulator. In Table 2, major component specifications of the 200-MW modulator are shown. The 200-MW modulator circuit can be divided by four major sections: charging, discharging, a pulse transformer assembly, and a klystron load. The primary power is adjusted by a phase-control system with six SCRs. To gain a fine DC output voltage regulation, active feedbacks of primary AC voltage and current as well as high voltage (HV) DC are supplied to the SCR gate trigger unit (GTU) as shown in the Fig. 2. Portion of charge in the filter capacitor is resonantly transferred to a pulse forming network (PFN) through a charging inductor and a charging diode. A De-Q'ing circuit is installed at the secondary of the charging inductor to regulate a PFN charging voltage. Final goal of a pulse-to-pulse beam voltage regulation in the 200-MW modulator is less than 0.5%. Details of the HV DC and beam voltage regulation results will be presented in [3]. Two parallel, fourteen section, type-E Guillemin networks are used in the PFN. The total PFN impedance is about 2.8 Ω. While PFN capacitors have a fixed value, PFN inductors are variable. The inductance variation enables us to tune a flat-top quality of an output beam voltage pulse. An end of line clipper (EOLC) circuit is employed to remove excessive negative voltage swing on PFN capacitors and a thyratron. The thyratron used in the 200-MW PLS modulator is ITT F-303. Specifications of the ITT F-303 thyratron are listed in Table 3.

Table 3: 200-MW thyratron (ITT F-303) specification

Description	ITT spec.	PLS spec.	
		60 Hz	180 Hz
Peak power (MW)	200	202	
Ave. power (kW)	200	91	273
Peak anode V (kV), epy	50	47	
Peak anode I (kA), ib	15	8.6	
dib/dt (kA/μs)	50	10.75	
Ave. anode I (A DC)	8 in air 12 in oil	3.87	11.61
epy x ib x PRR	300×10^9	24.3×10^9	72.8×10^9
epy x dib/dt x PRR	---	30×10^{15}	91×10^{15}

As shown in the table, the thyratron does not have a capability of handling the full designed specification of the 200-MW modulator. However, it can of course handle the full required parameters in current PLS linac. Forced air cooling is used for the thyratron. Two triaxial cables in parallel are used to make electrical connections between the PFN and a pulse transformer. By using the double configuration, stress on the cable [4] is reduced. Components in the pulse transformer tank are immersed in high voltage insulating mineral oil. The klystron load is placed on top of the transformer tank. The klystron impedance seen at the primary of the pulse transformer is 2.8 Ω. PFN impedance is adjusted so that there is a positive mismatch (~5 %) between PFN and load. The method of positive mismatching has many advantages over negative mismatch and not significantly affect thyratron recovery time [2,5]. In Fig. 3, an arrangement of major components in the 200-MW modulator cabinet is shown. As shown, the modulator has a control cabinet, a main cabinet, and a circular tank with a klystron load. The control rack encloses all low voltage monitor, control, and interlock compartments. The main cabinet is separated in two parts; charging and discharging cabinets. The charging cabinet covers from 480V AC primary power line inlet to de-spiking circuit. The discharging cabinet encloses PFN and thyratron related circuits. Low voltage controllers related to the thyratron and klystron is mounted on the discharging cabinet. A center metal plate separates the charging and discharging cabinet in order to reduce noise coupling between the two compartments. There are two BNC boxes and four filter boxes in the modulator. Double shielded 50 Ω coaxial cables and ferrite cores are used to treat signals through the BNC boxes in order to reduce noise level during discharging. All multi-conductor signal wires coming in and out of the main modulator cabinet goes through filter boxes in which EMI filters are installed. Completely enclosed metal wire ducts are also installed on the roof of the 200-MW modulator main cabinet. Signal wires connecting to the modulator circuit escape from the main cabinet as early as possible and go through the duct to their destination. This effectively reduce the chance of high frequency noise coupling. In this configuration, the whole 200-MW modulator cabinet including the tank assembly is considered as one completely enclosed faraday cage. A single point ground is effectively used for the whole modulator circuit. Points where grounds are connected to form loops are isolated by means of filters and transformers.

VI. REFERENCE

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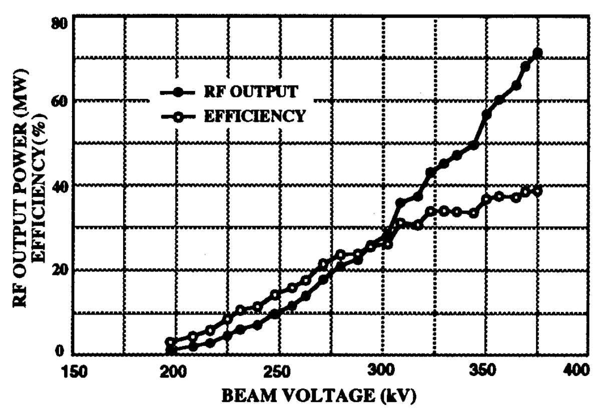

Fig. 1: Plot of beam voltage versus E-3712 klystron RF output power. 150-MW modulator is used to measure the data. (ISOL = 16.5 A, RF drive power = 250W, PRR = 50Hz , Heater power = 440W)

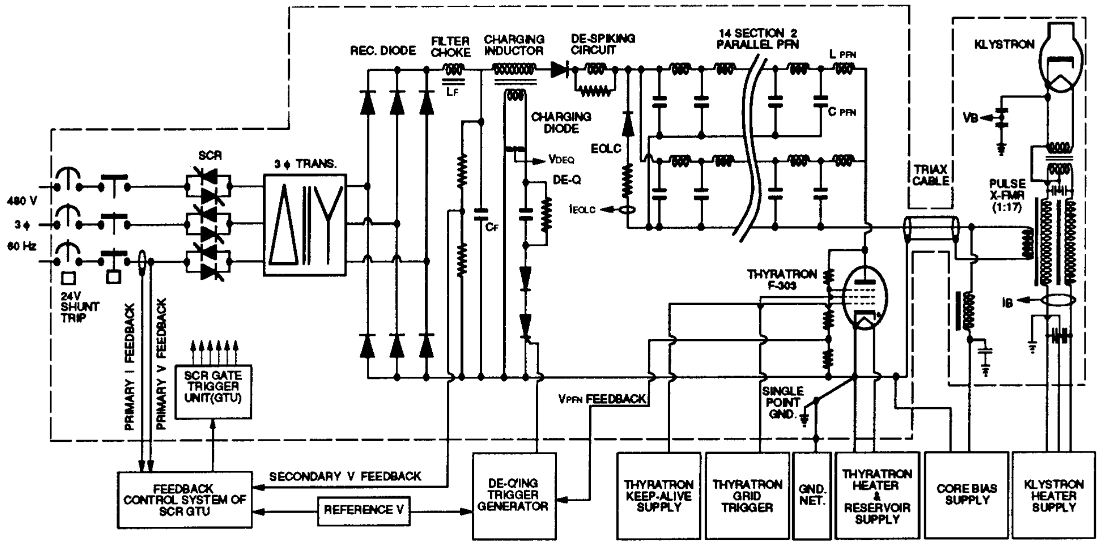

Fig. 2 : Simplified circuit diagram of 200-MW modulator.

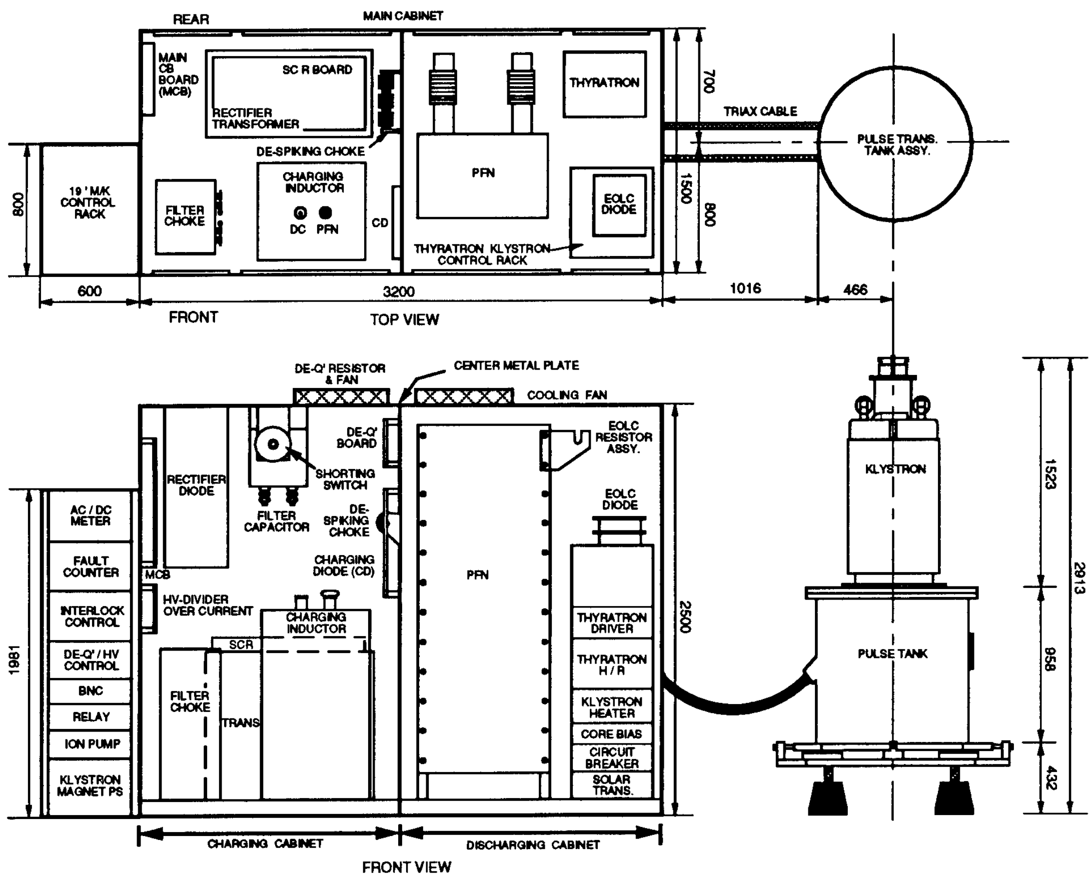

Fig. 3 : Configuration of main components in 200-MW modulator cabinet (units are in mm).